Technical Report Documentation Page

1. REPORT No.

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE

Control of Embankment Compaction By Nuclear Testing

5. REPORT DATE

January 1966

6. PERFORMING ORGANIZATION

7. AUTHOR(S)

Smith, Travis W. and Daniel R. Howe

8. PERFORMING ORGANIZATION REPORT No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

State of California
Highway Transportation Agency
Department of Public Works
Division of Highways

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

12. SPONSORING AGENCY NAME AND ADDRESS

13. TYPE OF REPORT & PERIOD COVERED

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This is a cooperative project undertaken with the U.S. Bureau of Public Roads and is federally financed with the one and one-half percent research funds.

16. ABSTRACT

The Materials and Research Department of the Division of Highways is currently undertaking an extensive research program to evaluate the application of nuclear soil gages to contract compaction control. The basic goal of this study is to determine the feasibility of nuclear equipment and methods for future use in California highway construction. The decision as to whether or not the present "Sand Volume" method is to be replaced with nuclear testing, for determining inplace moisture and density, will rest on the outcome of this research project.

This research project represents the culmination of an intensive series of nuclear studies, undertaken over a period of about six years. While the early investigations indicated several serious technical and operational difficulties with nuclear devices, more recent work is demonstrating that the major deficiencies are gradually being overcome by the industry and the engineering profession. Also other states, such as Pennsylvania, Colorado and Oklahoma, have made considerable experimental use of nuclear equipment for Compaction Control.

As a consequence it is felt that the time has arrived for a large scale experimental application of the nuclear method on actual construction.

17. KEYWORDS

18. No. OF PAGES:

33

19. DRI WEBSITE LINK

http://www.dot.ca.gov/hq/research/researchreports/1966-1967/66-07.pdf

20. FILE NAME

66-07.pdf

STATE OF CALIFORNIA
HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

CONTROL OF EMBANKMENT COMPACTION BY NUCLEAR TESTING

By
Travis W. Smith
Assistant Materials and Research Engineer - Foundation

and

Daniel R. Howe
Soils Engineering Associate

Presented at the Eighteenth Annual California Street and Highway Conference of the Institute of Transportation and Traffic Engineering, Berkeley Campus, University of California.

January 27-29, 1966

66-07

CONTROL OF EMBANKMENT COMPACTION BY NUCLEAR TESTING

By

Travis W. Smith*

and

Daniel R. Howe**

INTRODUCTION

The Materials and Research Department of the Division of Highways is currently undertaking an extensive research program to evaluate the application of nuclear soil gages to contract compaction control. The basic goal of this study is to determine the feasibility of nuclear equipment and methods for future use in California highway construction. The decision as to whether or not the present "Sand Volume" method is to be replaced with nuclear testing, for determining inplace moisture and density, will rest on the outcome of this research project.

This research project represents the culmination of an intensive series of nuclear studies, undertaken over a period of about six years. While the early investigations indicated several serious technical and operational difficulties with nuclear devices, more recent work is demonstrating that the major deficiencies are gradually being overcome by the industry and the engineering profession. Also other states, such as Pennsylvania, Colorado and Oklahoma, have made considerable experimental use of nuclear equipment for Compaction Control.

---

*Assistant Materials and Research Engineer - Foundations Materials and Research Department, Division of Highways, Sacramento, California
**Soils Engineering Associate, Materials and Research Department, Division of Highways, Sacramento, California

As a consequence it is felt that the time has arrived for a large scale experimental application of the nuclear method on actual construction.

The present research program is arranged so that nuclear gages are being used on eleven projects in ten of our eleven highway districts during the 1965-66 construction seasons. This scheme provides a broad range of various soil types, terrain, climatic conditions and construction operations which should represent a good cross-section of typical situations normally encountered in California highway construction. It can be seen on the California map, shown in Figure 1, that the projects are variously located in the south eastern desert regions, the coastal areas, the central valleys and the mountain ranges. Quantities of embankment and structural section material vary from about one-quarter million cubic yards to fifteen and one-half million cubic yards per project. This means that the nuclear gages are required to check compaction compliance on a total of over 45 million cubic yards of material.

In order to achieve the goal of being in a sound position to make the critical decision, it will be necessary to carefully evaluate many facets of the nuclear operation. Such items as the administrative aspects, practicality and technical credibility of a tentative test method, health safety, training of personnel, technical feasibility and durability of various makes of nuclear equipment, contractor's attitude, etc., will all be scrutinized in detail. This study will also provide a "backlog" of experience and "knowhow" in the event that a decision is reached to adopt the nuclear method as the standard means of compaction control.

This is a cooperative project undertaken with the U.S. Bureau of Public Roads and is federally financed with the one and one-half percent research funds.

HISTORY

With the dawning of the nuclear era, many applications of radioisotopes to the testing of materials have been developed. Among the earliest investigations, into ways of determining densities and liquid quantities in the ground, were studies undertaken by the petroleum industry in the late 1940's. Their experiments were largely concerned with measuring oil content and densities of oil bearing formations. Shortly thereafter, in 1949 and 50, Cornell University conducted experiments in determining subsurface soil density and moisture by nuclear methods. Portable nuclear gages, which measure soil density and moisture from the surface of the ground, were developed in the mid 1950's as a consequence of the efforts of various investigators.

In the period from 1954 to 1958 the Materials and Research Department, in cooperation with University of California, undertook extensive studies involving the use of radioisotopes to measure the changes in density and moisture in soft foundation soils. These studies proved the usefulness of subsurface measurements.

Our investigation of portable nuclear surface gages began with the purchase of an early model device from the Nuclear Chicago Co. in 1959. From 1959 to 1961, attempts were made to use this surface gage on various highway projects. Unfortunately equipment failure was so frequent in 1959 that very little usable data was obtained. However in 1960 and 1961 the device was more reliable and considerable comparative data was obtained with the sand volume test from field studies. It was found that the densities indicated by the nuclear device ranged from zero to fifteen pounds higher than those obtained by the sand volume test.

As a consequence of these and other findings from the preliminary field trials, an extensive laboratory study, followed by another more elaborate field investigation, was undertaken in 1962. At about this time a Hidrodensimeter surface gage was purchased from Tellurometer, Inc. and included in the study.

In the laboratory phase of the program, eight different soils, from various parts of the state, were compacted in a circular steel mold two feet in diameter and one foot in depth. Specimens of each soil were fabricated at various densities and moisture contents. Comparisons were then made between nuclear densities and the density of the soil compacted in the mold. Likewise comparisons were made between nuclear and oven dry moisture determinations. The "true" soil density was determined by several methods given as follows:

(1) Calculated by soil weight and mold volume

(2) Sand volume test

(3) Chunk specimens

The findings of this laboratory study were not too encouraging. To obtain maximum accuracy in density determinations it was found that it is necessary to develop individual calibration curves for each soil. At the 90% confidence level the nuclear readings were within 3-1/2 pounds per cubic foot (p.c.f.). When one calibration curve is used for all soils, as recommended by the gage manufacturers, the 90% confidence limits are about 7 p.c.f. The nuclear gages were found to be very sensitive to the surface condition of the soil with respect to the seating of the probe. Experiments also indicated that, for the gages used, the effective depth of the density determination was only 3 to 4 inches and that the volume of soil being measured was about one-tenth cubic foot.

The field phase of the investigation was begun, with the same gages, in the period near the termination of the laboratory work. Ten highway projects within 100 miles of Sacramento, which were under construction in the summer of 1962, were selected for this study. Again, as in the laboratory study, the primary objective involved the comparison of nuclear density and moisture determinations with values obtained by other methods. No attempt was made, at this time, to utilize nuclear testing for compaction control purposes.

In general the findings in the field investigations confirmed those ascertained in the laboratory except that somewhat broader variations were noted in the field nuclear determinations. The 90% confidence limits ranged from 8-1/2 to 10 p.c.f. for density and about 1-1/2 to 4-1/2 p.c.f. for moisture. These values apparently reflect the adverse effects of operating under field conditions when compared to the laboratory where specimen fabrication, gage functioning, etc., are performed under the most ideal conditions.

As a result of this laboratory and field investigation, we were reluctant to be committed to nuclear control testing, without further study into ways of improving the method and equipment. The facts that (1) the seating problems and separate calibrations for each soil type tended to obviate any time advantage the nuclear test might have over the sand volume method, (2) equipment investment would be considerable for construction control on a statewide basis (approximately $4,000 per gage) and (3) we were not satisfied that the variations, indicated in the results, could be tolerated; all led to a conservative outlook towards nuclear testing.

The details of this early study are given in a paper entitled "Laboratory and Field Evaluation of Nuclear Surface Gages for Determining Soil Moisture and Density," prepared by Mr. William G. Weber, Jr., for presentation at the 43rd Annual Meeting of the Highway Research Board in January 1964.

In the year following our initial investigation, several new concepts of nuclear testing were developed and, of equal importance, the nuclear industry had come out with production models of a new type of portable gage. Up to this time the surface density gages were designed to measure the Compton backscatter effect from gamma radiation acting upon the soil. In this type of device both the radioactive source and detector tube are fixed in a shielded container (called a probe) which rests directly upon the surface of the soil as shown in Figure 2. The new type density gage utilizes the principle of direct "transmission" of gamma radiation from the source to the detector through the soil. In this case the detector is fixed inside the probe which is resting on the ground surface and the source is contained in a rod which is inserted into a pre-drilled or punched hole in the soil to any depth ranging from ground surface to 12 inches. A schematic diagram of a transmission gage is illustrated in Figure 3. Incidentally, there is a manufacturer who makes a transmission probe of the style shown in Figure 3, while latest models of gages from another manufacturer reverses the arrangement by placing the detector in the rod and the source in the probe. A schematic diagram of a typical moisture probe is shown in Figure 4.

With the advent of the transmission gage and the new concepts, another major laboratory study was undertaken in 1964. This time the Materials and Research Department cooperated jointly with the Department of Water Resources in the undertaking, since both departments were engaged in similar endeavors. The research project had several objectives which are given as follows:

(1) Evaluate the laboratory accuracy of both transmission and backscatter gages when used on soil specimens fabricated in a mold.

(2) Compare the transmission and backscatter techniques of nuclear density determinations.

(3) Evaluate the application of such concepts as, the use of scintillation detectors, energy discrimination, collimation (i.e., drawing the source up into the shield to cause a "beam like" effect of radiation from backscatter gages), etc.

The findings of this study were much more encouraging. The transmission tests indicate a marked improvement over the conventional backscatter method, in several ways. For one thing accuracy of density determinations were significantly increased when transmission is used. The transmission test had a standard deviation of about 2-1/2 p.c.f., which, it is felt, approaches the accuracy to which the soil samples were prepared. The conventional backscatter type test demonstrated a standard deviation of about 4-1/2 p.c.f. which is similar to the previous findings. The transmission test was also found to be far less sensitive to the roughness of the soil surface at point of probe contact. This minimizes the time and effort involved in site preparation. Another big advantage of the transmission method appears to be that one calibration curve can be applied to most soils. This also results in considerable savings in time and effort, in that only occasional check comparisons with the sand volume test, where unusual changes in soil type were encountered, would suffice in most cases.

One rather startling outcome, in connection with the backscatter method, concerns the pronounced effect upon the accuracy of the density determinations that collimating the source had. It lowered the standard deviation of the results from 4-1/2 to 2-1/2 p.c.f. This results in the backscatter gage becoming more comparable to the transmission gage. It is our understanding that at least one manufacturer of backscatter gages will in the near future produce a device which includes the collimation principle.

A departmental report, covering this work, has recently been prepared and submitted to the Bureau of Public Roads for approval. The title of this report is "A Basic Study of the Nuclear Determination of Moisture and Density."

In view of the promising outlook of these new developments, it was decided that the overall nuclear density program had come to a stage where a pilot study, which examined both the practical and technical aspects of nuclear testing in connection with construction control, was indicated. As a consequence a two phase field program was undertaken in the summers of 1964 and 1965.

One of the phases of the study consisted of using one nuclear soil gage and a technician, operating out of headquarters laboratory in Sacramento, to cover five projects located in our highway districts 03 and 10. While the basic method of compaction control on these jobs was still our "old reliable" sand volume test, attempts were made to perform parallel nuclear density and moisture tests whenever compaction control testing was needed. This procedure was primarily designed to test the practical aspects of controlling a number of projects at one time from a central field laboratory, as is the current practice in several of our districts. Another aim was to make preliminary trials of a new "multiple testing concept" which appeared to have promise. The results of this phase provided much useful information and data.

The other phase of the field study involved the actual specifying of nuclear control testing, in the contract special provisions of a project, in lieu of the sand volume method.

This was our first real trial "under fire" of nuclear testing and it was intended that the method would "sink or swim" entirely on its own merits.

The contract selected for this purpose was a project in the Eureka Highway District on U.S. 101 near Garberville. This contract involved the placement of approximately 615,000 cu. yds. of fill and considerable structure backfill, permeable material, base and subbase. The project proved to be ideally suited for the study in that a wide variety of conditions and materials were encountered.

Training of project personnel was undertaken in the spring of 1964. The resident engineer and two technicians were sent to Sacramento for a concentrated one week's course of instruction. Upon conclusion of the training the project personnel returned to the district with the nuclear equipment and proceeded with testing operations.

The successful outcome of this construction control trial in combination with the work accomplished in the other phase of the field study, has provided the basis for developing an effective and rational test method. Departmental reports have been prepared on each of these phases. The resident engineer is very satisfied with the quality of testing and has indicated that he is desirous of utilizing the nuclear method on another project. The nature of the compaction, revealed by the nuclear tests, is very realistic and indicates that the method is feasible for construction control. It is primarily the outcome of these recent field and laboratory studies that influenced the decision to undertake the present statewide construction control study outlined in the introduction and described in detail in the following section of this paper.

During this recent period of intensive investigation of portable nuclear gages, there was also another important nuclear study being carried on by the Materials and Research Department in cooperation with the Construction Department. This research project involved the trial of a truck mounted nuclear gage, called "The Road Logger" which is illustrated in Figure 5. This equipment is designed to produce a continuous "strip chart" recording of the density and moisture of the material over which the truck travels.

The Road Logger was leased from the Lane Wells Co. of Houston, Texas, for use by us in October and November of 1964. The equipment was used on 28 construction projects in nine highway districts for periods varying from one to five days per project. The operation of the Road Logger, on the various projects, was noted with respect to characteristics, deficiencies and limiations. Evaluations were made in terms of correlation with other tests, economics and potential for construction control purposes.

In general it appears that the Road Logger is technically feasible for construction control of both embankments and structural section materials (except surfacing). The equipment can log from three to seven miles of roadbed in a normal day's operation and under normal testing speeds and time constant, measures a volume of about six cubic feet of soil. The depth of soil affecting the nuclear readings is about five to seven inches and the portion of soil nearest the gage does not appear to affect the readings as much as in the case with portable gages. Minor variations such as rocks, variation in air gap, surface roughness apparently do not affect the measurements. The correlation of the sand volume and nuclear tests is as good or better than that found with the portable gages.

There are, however, several limitations in the use of the Road Logger. In embankment construction it is necessary to blade the surface of the fill where sheepsfoot rollers are used. On rocky fills the speed of travel must be reduced to avoid excessive vibration or jolting of the equipment. This, of course, reduces the mileage which can be logged per day. The use of the Road Logger is only practical where fairly long "reaches" of roadbed can be tested continuously. Spot locations, requiring considerable stopping and starting, maneuvering, or turning around, and structure backfill are not practical for this mobile equipment.

The greatest disadvantage, in the application of the Road Logger, appears to be the economic element. When using this equipment for compaction control, it is estimated that about 100 miles of logging could be performed per month. This would involve a total cost of operation of about $5,000 per month. The cost of the present compaction control is in the neighborhood of $1,000 per month per project for a man and vehicle. This would indicate that about four to five men would need to be replaced to economically justify the use of the Road Logger.

As a consequence it appears that the following minimal conditions would have to exist, in one degree or another, in order to provide economic justification for this equipment:

(1) Operate concurrently on several medium or large projects which are either adjacent to each other or within a radius of 50 miles.

(2) Projects must involved a large volume of earthwork being placed rapidly.

(3) There must be three or more normal high speed contractor operations.

While we intend to explore the application of the Road Logger further, with the possibility of actually specifying it as the only means of control on several projects, our main efforts are presently being concentrated on the continued investigation of portable nuclear gages for compaction control.

With the approval of the Bureau of Public Roads, we have published a report on the "Field Evaluation of the Lane-Wells Road Logger," dated June 9, 1965.

PRESENT STATEWIDE NUCLEAR CONSTRUCTION CONTROL STUDY

In the introduction to this paper, a brief summary was given which outlined the scope and purposes of our current statewide nuclear research program. We would now like to cover some of the more pertinent details which may be of interest.

Ten nuclear soil gages were purchased from four manufacturers at a total cost of about $45,000. Of the four makes, two are backscatter types and two are transmission gages.

There are three basic types of radioisotopes variously employed in these devices which have radioactive strengths ranging from 3 to 33 millicuries. Possession of these sources is authorized under license from the California Department of Public Health. Table I indicates the gage makes, manufacturer, types, and types of radioactive material used in this study. Photographs illustrating the operation of these gages under typical field conditions are shown in Figures 6 through 10.

TABLE I

Gage Make	Manufacturer	Gage Type	Radioactive Source
Hidrodensimeter	Viatec Limited South Africa	Transmission	Ra-Be
Nuclear Chicago	Nuclear Chicago Co. Des Plaines, Ill.	Backscatter	Ra-Be
Numec	Nuclear Materials & Equipment Corp. Apollo, Pa.	Backscatter	Ce 137 Am-Be
Troxler	Troxler Electronic Laboratories, Inc. Raleigh, N. C.	Transmission	Ra-Be

Table II illustrates the various details of the eleven projects and the gage assignments. The resident engineers and at least two technicians from each project have been trained in basic nuclear physics, health safety, gage operation and the test method by personnel of the Materials and Research Department. The contract special provisions for each contract contain a clause that specifies the nuclear method, for determining in-place densities and moistures "in lieu of the sand volume test," as the only means of compaction control.

The resident engineers are responsible for the application of the nuclear gages with regard to the construction aspects of their respective projects, interpretation of the data for construction control purposes, maintenance of weekly health safety records, physical examinations, and considerations of nuclear source storage and transport. Health safety is governed by regulations administered by the California Department of Public Health. Each operator and the resident engineers are equipped with film badges and dosimeters to monitor exposure.

The Materials and Research Department is accumulating the data records from the projects and will be responsible for the data analysis, from the research standpoint, and writing of the research reports. We also provide consultation services to the projects on nuclear matters and handle the maintenance and repair of nuclear equipment.

The Test Method No. Calif. T 231-B is established as the standard for the specification control of compaction on each of the projects. This method evolved from our past work with nuclear gages, especially the contract control study on U.S. 101 in our Eureka highway district (Dist. 01), described previously in this paper.

The method utilizes the "multiple testing" and "area concept" techniques. In this approach, a compacted "area" (or zone) of roadbed having the same soil type throughout, is divided into at least three sections. A minimum of two sites are selected at random within each section and in-place nuclear density and moisture tests are performed at each location within all sections in the area. Relative compaction values are then calculated for each test density found, utilizing the maximum density obtained on the soil type from the Impact Compaction test. The average relative compaction of all tests within the area, is then used as the basis for determining whether the area passed or failed to meet the minimum specification limit for the material in question. In addition, for an area with a passing average to fully qualify as "passed", at least two-thirds of the individual tests within the area must also have passing relative compaction values. Figure 11 gives a typical example of a compaction control determination.

In summarizing the program to date, there appears to be both advantages and disadvantages in applying the nuclear method to compaction control. On the credit side of the ledger, it is fairly apparent that broader coverage of compaction is being accomplished. The contractor is being provided with an answer sooner than ever before. Some enthusiasm is being noted on the part of contractors, which if it "catches on" could possibly affect a reduction in bid prices. One contractor has stated already that if he knew that nuclear testing would be used on his next job, he would lower his price on roadway excavation by a penny a yard. Nuclear testing is often performed on materials and in locations where it is not possible to undertake the sand volume test. (e.g., rocky or sandy cohesionless materials).

On the debit side, we have the high cost and complexity of the devices. Maintenance could be a major and continuing problem with these electronic devices which are nearly as complicated as television sets. Unfortunately trained specialists for repair of this equipment may not be readily available. The most serious aspect of equipment breakdown is the interference with job operations caused by "downtime" for repairs. The use of backup devices would tend to minimize the affect of gage shutdown. However, in the case of backscatter devices, part of the advantage of alternate gages would be lost in the time required for recalibration. Experience in this study so far indicates a total of 38 instances of equipment failure, in a ten month interval, which resulted in varying "out of service" periods. It remains to be seen if this rate of maintenance difficulties represents typical expectations for the future. Table III summarizes the nature of the malfunctions encountered.

Health safety and the constant awareness of working with a potential hazard would present some problems, especially in the administrative category. State law requires that the radioactive sources be "wipe tested" at least twice a year. The inconvenience to the job and cost of this item would not be inconsiderable.

All in all these disadvantages do not appear insurmountable, but in the "final analysis" the big question is, will the advantages outweigh the disadvantages?

THE FUTURE

If the statewide project is as successful as we have hopes it will be, we will make extensive use of nuclear equipment for the control of compaction. Within a year we will know the results and, if favorable, we can start a transition from sand volume testing to the nuclear method. One word of caution, however; it is not likely that we can or will attempt to equip every project with nuclear devices. There is a point of "diminishing returns" where projects are so small that the investment becomes too great. In these cases either the use of the sand volume test will be continued or a "central laboratory" arrangement may be made to handle a number of small projects with a nuclear gage. In any event the transition will have to be gradual and the specifications will probably contain provisions for the use of optional methods.

There is already some evidence of interest in expanding nuclear control testing. We have had a request from District 01 to incorporate nuclear testing in a major project, with large fills, on U.S. 101 near Cummings. As a consequence, a specification is being written for the contract to accomplish this purpose. District 05 is using a nuclear gage, under contract change order, on an FAS project north of Hollister. District 06 has processed a contract change order to undertake nuclear testing on a project on route 33 just south of the existing nuclear project near Firebaugh. Ventura County is including nuclear testing in a contract, on a county road in the area, and intends to employ their own nuclear gage. These projects will not be included in our current research study.

In order to accommodate these new projects and also provide ourselves with "backup" gages, we are in the process of ordering two new devices. Rather than purchase a particular make and model, we have written an equipment specification which embodies all of what we consider are desirable features on the basis of our experience to date. Basically the gage will be a transmission type with the detector in the rod, which goes below ground, and the source will be contained in the probe case on the ground surface. This device may also be used as a backscatter gage. Most of the features being asked for are avilable in various makes of production gages today and we believe that a qualified manufacturer can provide the specified item.

One of the aspects of our compaction control testing today, which is time consuming and will not be remedied by introduction of nuclear in-place testing, is the Impact Compaction test. This test provides the compaction standard, in the form of a laboratory maximum density, from which relative compaction values are calculated. The method is not only time consuming but laborious and cumbersome. We currently have a research project under way on this problem in which we hope to embody nuclear equipment and a new concept. If this proves to be successful along with in-place nuclear methods, then we will have gone the "full circle" in modernizing compaction testing to keep pace with present day "high rate" construction practices.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the many individuals who, over the years, have participated in the research projects described in this paper. The various studies were under the direct supervision of Mr. William G. Weber, Jr.

Most of the work undertaken from 1964 to the present time was performed in cooperation with the Bureau of Public Roads. Since they have not yet had an opportunity to review this paper, the conclusions and opinions expressed are not necessarily those of the Bureau.

REFERENCES

(1) "Laboratory Studies of Nuclear Surface Moisture and Density Gages." A Materials and Research Department Report, October 10, 1962.

(2) "Report on Field Studies During 1962 of Nuclear Surface Moisture and Density Gages." A Materials and Research Department Report, July 24, 1963.

(3) "A Plan for Expediting the Use of Statistical Concepts in Highway Acceptance Specifications". A report prepared for the Department of Commerce, Bureau of Public Roads, Office of Research and Development by Miller-Warden Associates Raleigh, N. C., August, 1963.

(4) "Laboratory and Field Evaluation of Nuclear Surface Gages for Determining Soil Moisture and Density" by W. G. Weber, Jr., presented at the 43rd Annual Meeting of the Highway Research Board, Jan. 13-17, 1964.

(5) "Field Evaluation of the Lane-Wells Road Logger." A Materials and Research Department Report, June 9, 1965.

(6) "Compaction-Myth or Fact?" by J. Frank Jorgensen and Robert O. Watkins, presented at the 44th Annual WASHO Conference, June 16, 1965.

(7) "Report on the Field Use of a Nuclear Soil Gage on Several Concurrent Construction Projects in Districts 03 and 10". A Materials and Research Department Report, August 18, 1965.

(8) "A Basic Study of the Nuclear Determination of Moisture and Density." A Materials and Research Department Report, November 1965.

(9) "The Application of a Nuclear Soil Gage to Construction Control." A Materials and Research Department Report, January 11, 1966.

TABLE II

DESCRIPTION OF PROJECTS INVOLVED IN NUCLEAR STUDIES

Dist.Co.Rte.	Location	Resident Engineers & Office Locations	Contractors	Amount of Earthwork	Type of Road Material	Soil Type	Gage Make & Type of Use
01-Hum-101	4 mi. S. of Scotia	H.A.Davis Rio Del	Green Const. Co.	3,400,000 cy 45,000 cy 162,000 T	Rdwy.Exc. I.B. AB & AS	Silt & Clay Shale Sandy Gravel	Hidrodensi-meter Transmission
02-Sha-5	At O'Brien	J.V.Kelly O'Brien	Ray Kizer Const. Co. R.A.Heinty Const. Co.	3,183,000 cy	Rdwy.Exc.	Sandstone Shale Sandy clay	Troxler Transmission
03-Sac-5	5 mi. No. of Sacramento	H.Lopez No.Sacto	Fredrickson & Watson Granite Const. Co.	16,500 cy 389,000 T	Rdwy.Exc. I.B.	Silty Clay Sandy clay	Hidrodensi-meter Backscatter
04-Ala-680	Nr. Scott's Corner	R.Warner Dublin	Gordon H. Ball Const.Co. Granite Const. Co. Price & Harris Const. Co.	3,360,000 cy	Rdwy.Exc.	Silty clay Clayey silt Sand & Silty gravel	Troxler Transmission
05-SBt-180	2 mi. S. of Hollister	F.A.Avila Tres Penos	Harm Bros.	130,000 cy 57,000 cy	Rdwy.Exc. I.B.	Clayey silt Silty clay	N/C Backscatter

Sheet 1 of 2 sheets

TABLE II (contd)

DESCRIPTION OF PROJECTS INVOLVED IN NUCLEAR STUDIES

Dist.Co.Rte.	Location	Resident Engineers & Office Locations	Contractors	Amount of Earthwork	Type of Road Material	Soil Type	Gage Make & Type of Use
05-SB-1,101	At Las Cruces	K.H.Miller Las Cruces	Milburn & Sansome Const. Co. Walter Bros. Const. Co.	2,730,000 cy	Rdwy. Exc.	Silty clay Clayey silt Sandstone Shale	N/C Backscatter
06-Fre-5	15 mi. southwest of Firebaugh	N.E.Humiston Firebaugh	Peter Kiewit Sons Co.	535,000 cy 2,970,000 T	Rdwy. Exc. I.B.	Silt Sand Scattered gravel	Numec Backscatter
07-LA-5	8 mi.north of Castaic	J.B.Byrne Castaic	Guy F.Atkinson Co.	15,400,000 cy	Rdwy.Exc.	Clay,clayey shale, silty sand	N/C Backscatter
08-SBd-40	At Newberry	Not assigned	Contract to be let in late spring 1966	410,000cy 4,050,000 T	Rdwy.Exc. I.B.	Sandy silt Sandy gravel Surface rock	Hidrodensimeter Transmission
10-Sta-5	2 mi.southwest of Patterson	C.Roderick Patterson	Peter Kiewit Sons Co.	3,680,000 cy	Rdwy.Exc.	Silty clay and gravel	Troxler Transmission
11-SD-5	San Diego 1 mile north of Old Town	G.A.Smith San Diego	R.E.Hazard Const. Co. W.F.Maxwell Co.	371,000 cy 901,000 T	Rdwy.Exc. I.B.	Silty sand Sandy clay & gravel	Numec Backscatter

Sheet 2 of 2 sheets

TABLE III

Nuclear Gage Malfunctions on Statewide Study from March 1, 1965 to January 1, 1966

Cause of Malfunction	No. of Occurrences
Scaler electronics	9
Probe electronics	3
Detector tube	2
Cable and/or connections	5
Binding of transmission rod	4
Timer	4
Moisture in gage	3
Battery	2
Battery Charger	3
Probe handle	1
Mechanical source elevator	1
Switches	1
Total Number of Occurrences	38

Nuclear Projects in Statewide Study Shown As ●
Additional Projects Shown As ▲

Figure 1

BACKSCATTER OR COMPTON TYPE NUCLEAR DENSITY GAGE

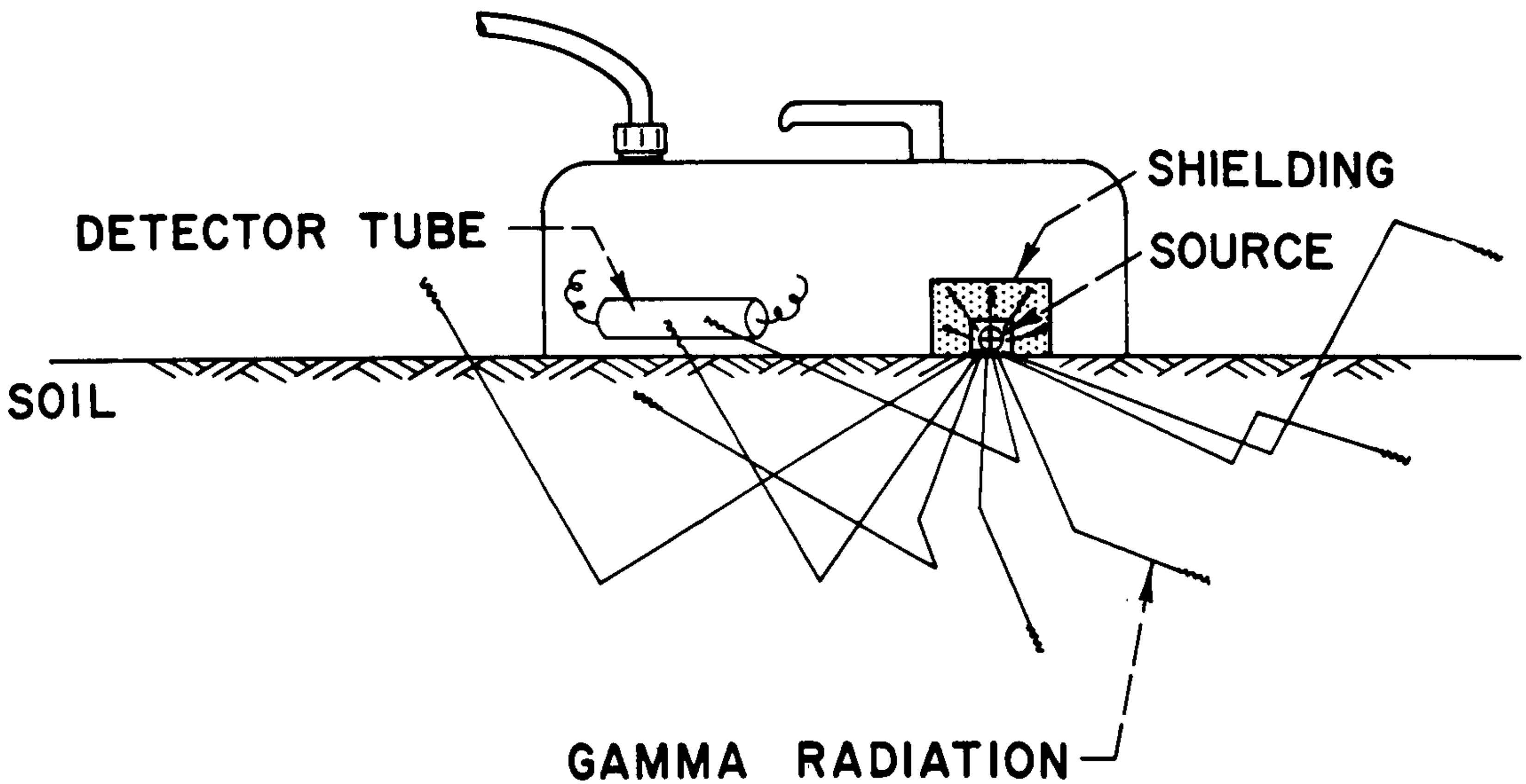


Figure 2

TRANSMISSION TYPE NUCLEAR DENSITY GAGE

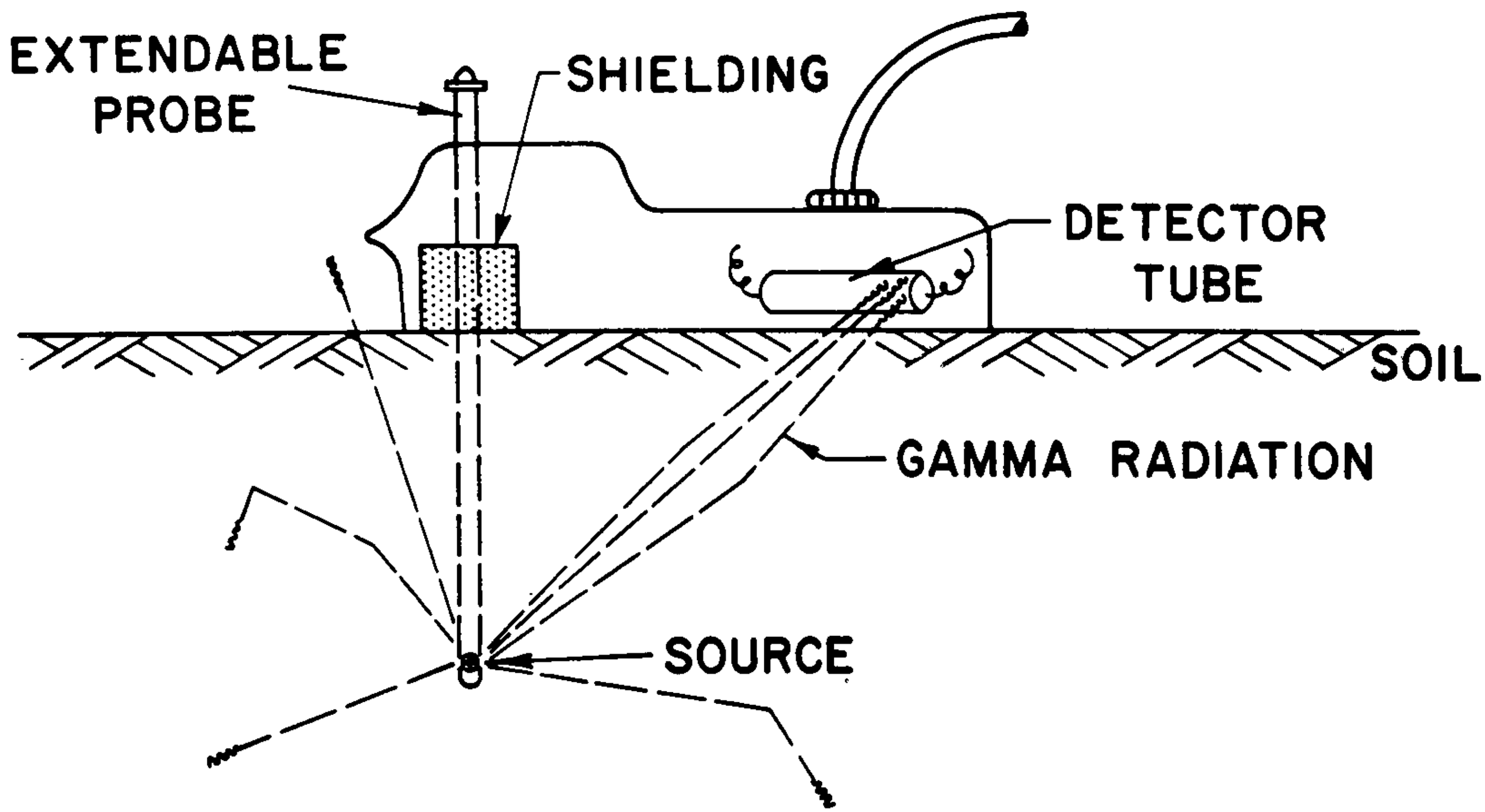


Figure 3

NUCLEAR MOISTURE GAGE

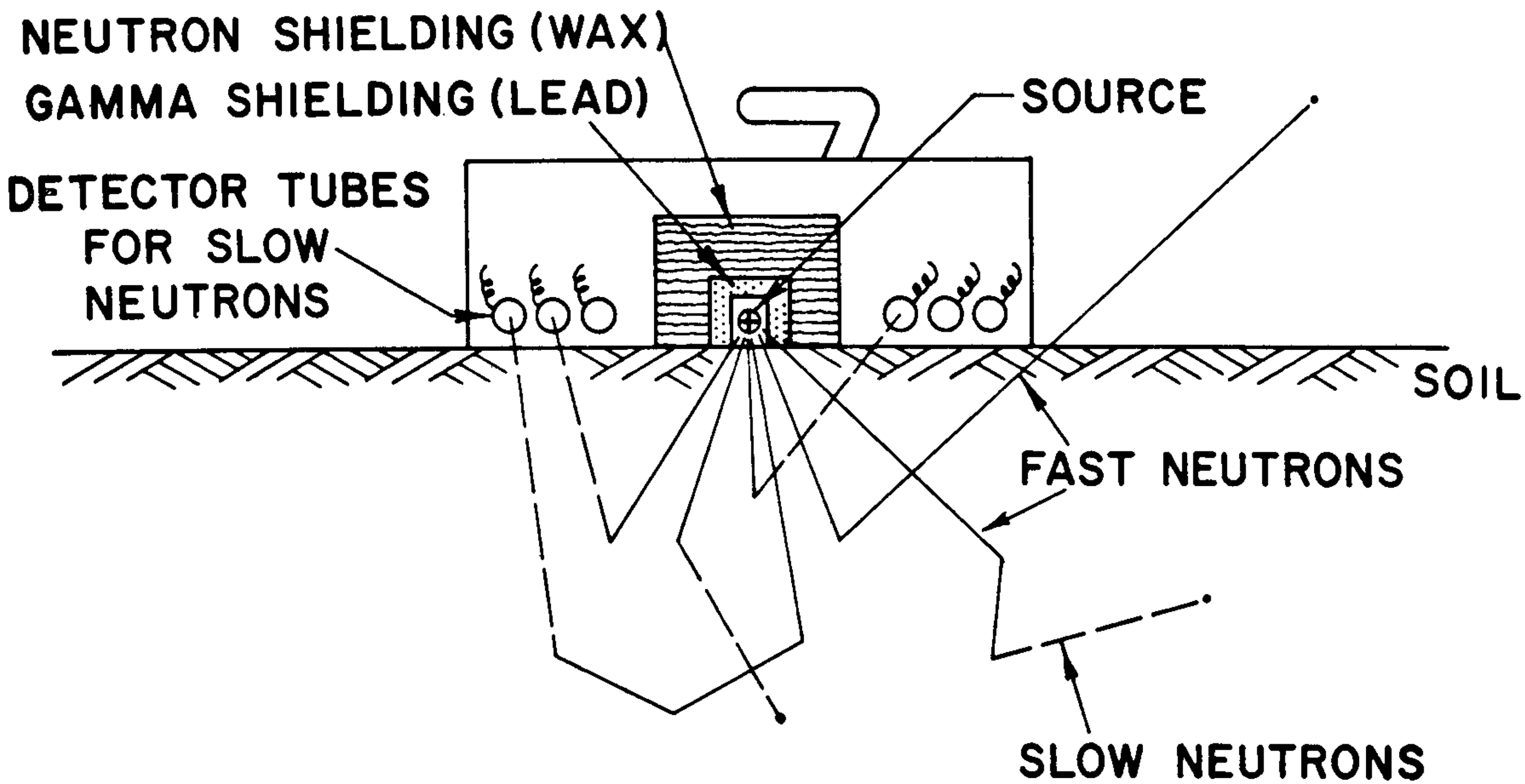


Figure 4

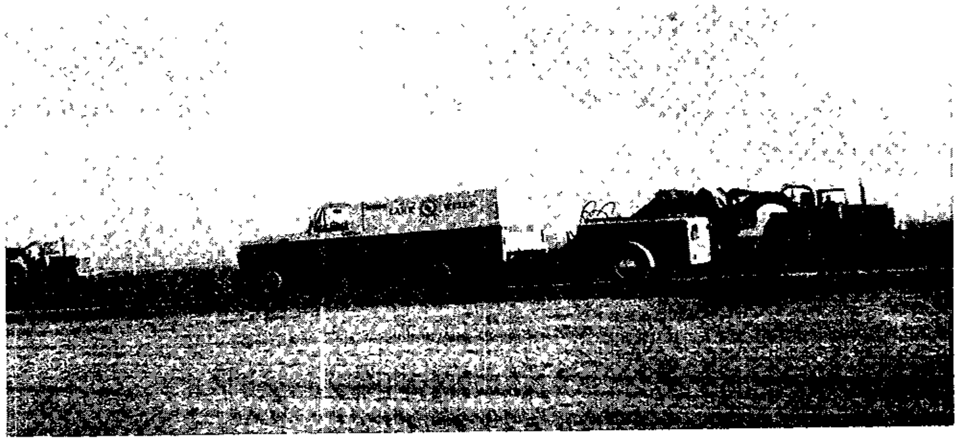


Figure 5. Lane Wells Road Logger in operation.

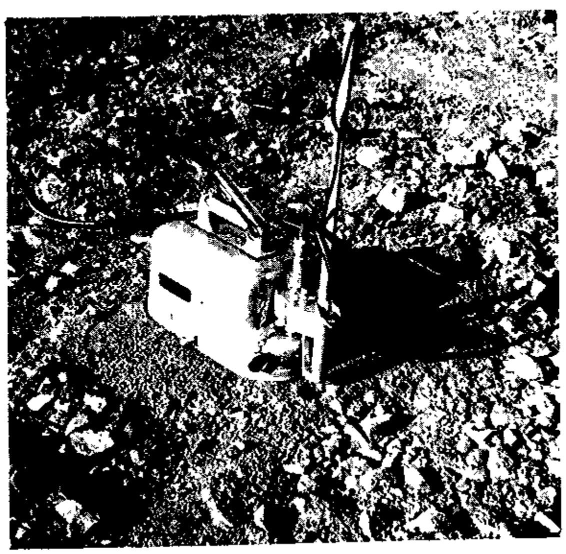


Figure 6. Hidrodensimeter transmission gage. Note hole in grade beneath rod.

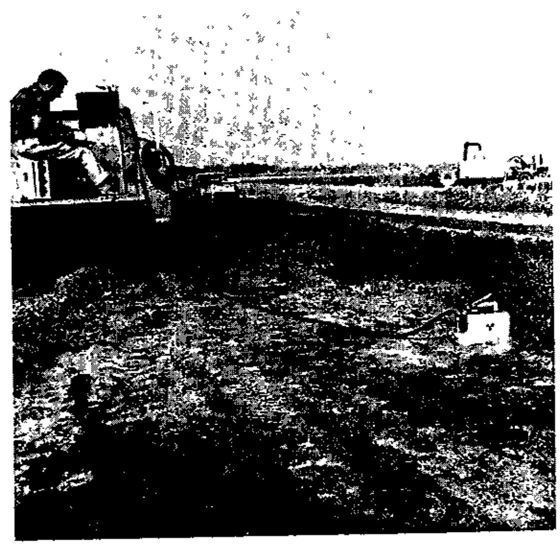


Figure 7. Hidrodensimeter transmission type gage used as a backscatter device (District 03).

Figure 8. Nuclear Chicago backscatter gage.

Figure 9. Numec backscatter gage.

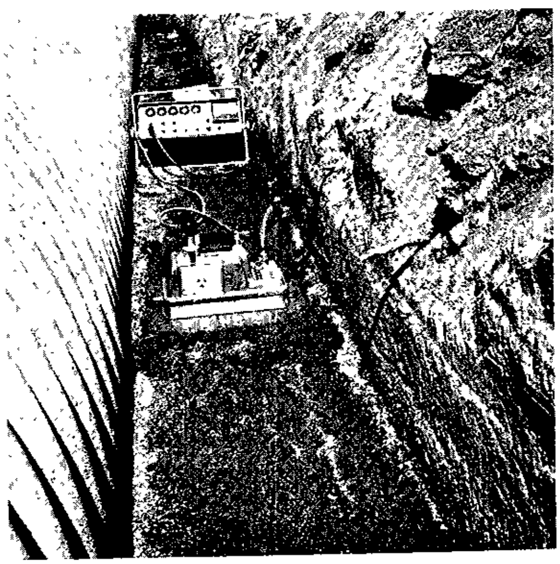
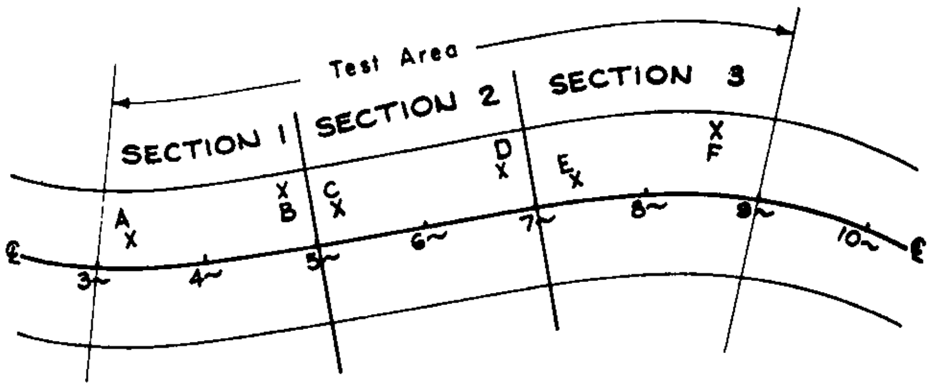


Figure 10. Troxler transmission gage being used in structure backfill.

EXAMPLE OF FIELD DENSITY CONTROL



Location: EXAMPLE PROBLEM
STA. 3+00 TO 9+00

Field Test Data:

SECTION	SITE	SITE DENSITY	RELATIVE COMPACTION SITE	RELATIVE COMPACTION SECTION AVG.
1	A	119	86	89
	B	128	92	
2	C	131	94	92
	D	125	90	
3	E	124	89	91
	F	129	93	
Relative Compaction, Area Average			6⟌544 90.7	

Laboratory Test Data: ADJUSTED WET DENSITY SITE D = 139#/ft³
90% = 125#/ft³

Figure 11